MicroBooNE – what are we worried about?

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For the MicroBooNE collaboration
FNAL xsec workshop
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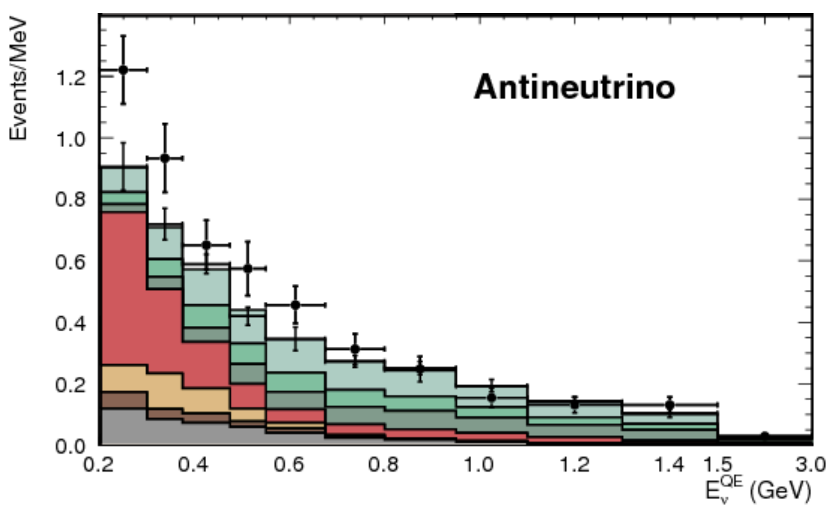
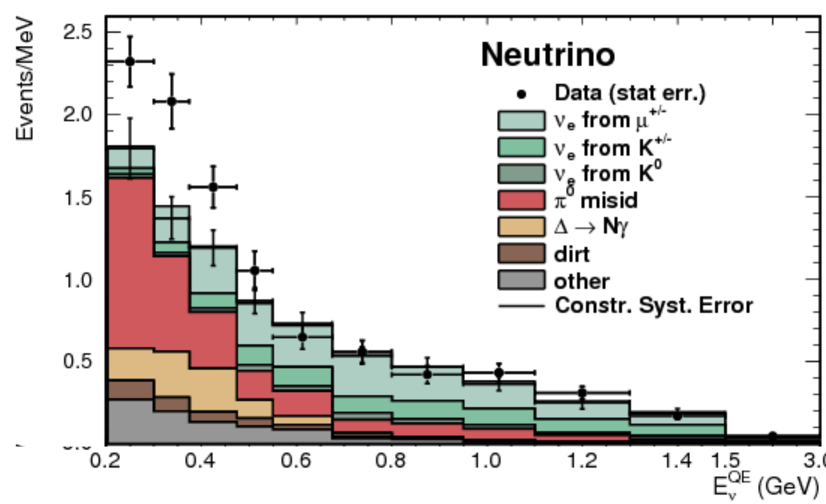
MiniBooNE's oscillation analysis in one slide

- Signal selection – **CC0π**
  - I.e. 1 muon ring, nothing else (or one electron ring)
- **NUANCE** used as baseline MC
- Then, ν_μ used to constrain ν_e prediction (via covariance matrix)
  - Everything done in **E_ν^{QE} space**





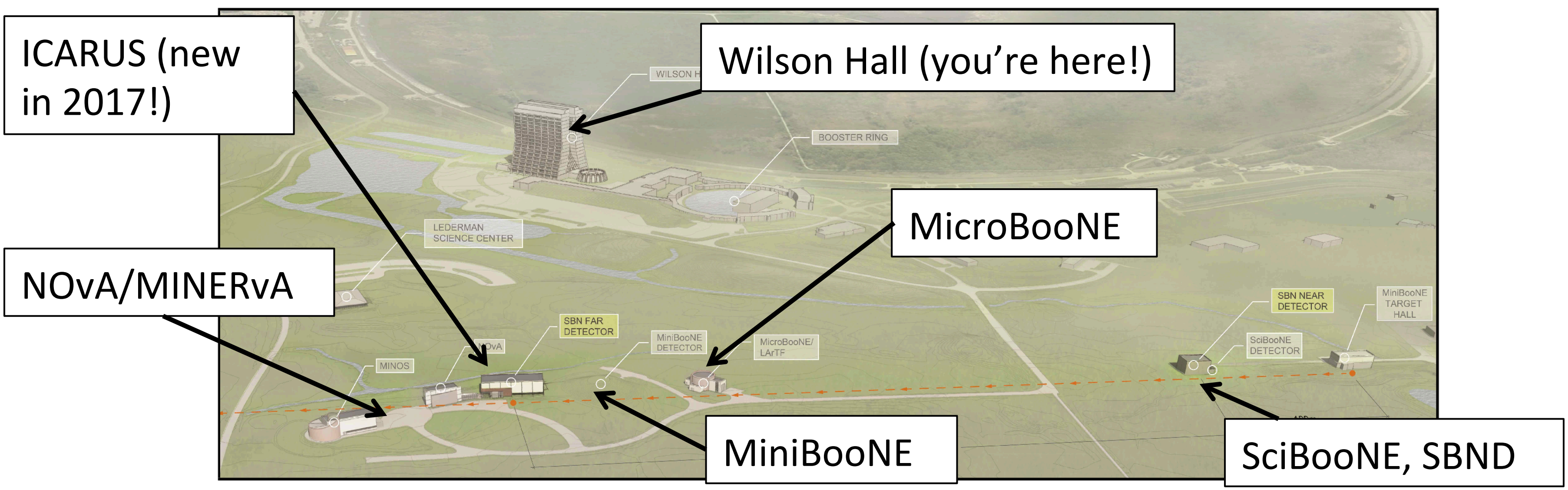
What MiniBooNE missed

- MiniBooNE's "high-M_A" puzzle led to the realisation we were missing various nuclear effects
  - **MEC** interactions, **short range correlations**, etc
- Many of these were really demonstrated by MiniBooNE for the first time, but…
- MiniBooNE never managed to incorporate these improved models into the oscillation analysis

- MiniBooNE also had a large background from neutral pions (though strongly constrained by their own data)
  - And an irreducible single photon background

MicroBooNE as a solution?

- MicroBooNE is a LArTPC also in the Booster Neutrino Beam
- Exposed to the NuMI beam too!
- Primary objective is to investigate the MiniBooNE Low Energy Electron-like Excess
- LArTPC selected due to high spatial resolution
  - Can reconstruct full neutrino interaction for different topologies
  - Lower thresholds, particularly for protons

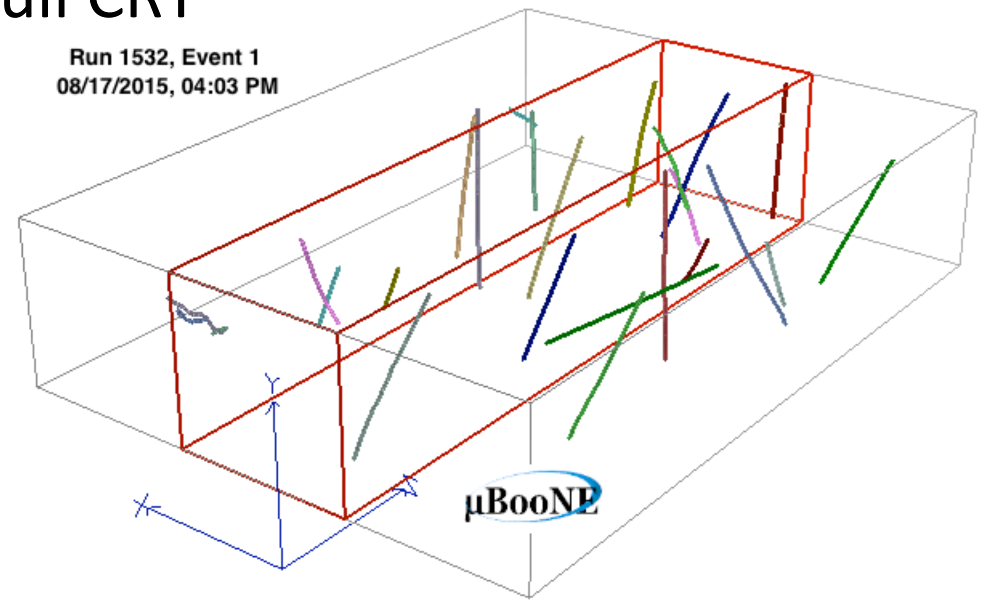


Cosmics at MicroBooNE

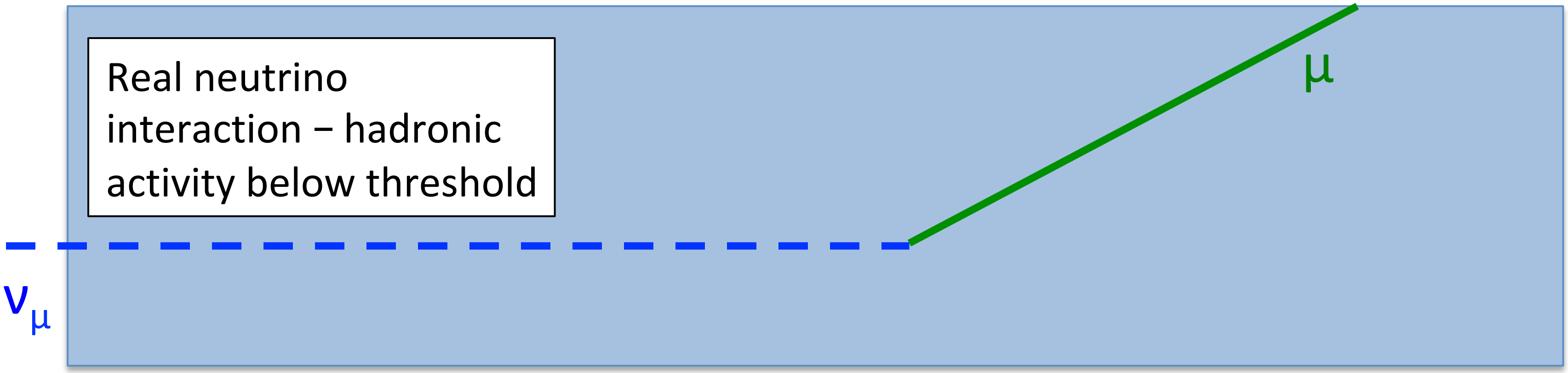
- MicroBooNE has **no overburden**
- Electron drift time is 2.2ms
  - Roughly **8 cosmics per drift window**
  - And 1 neutrino every 600 spills
- 1 year with **no cosmic ray tagger**, 1 year with partial CRT and remaining with full CRT

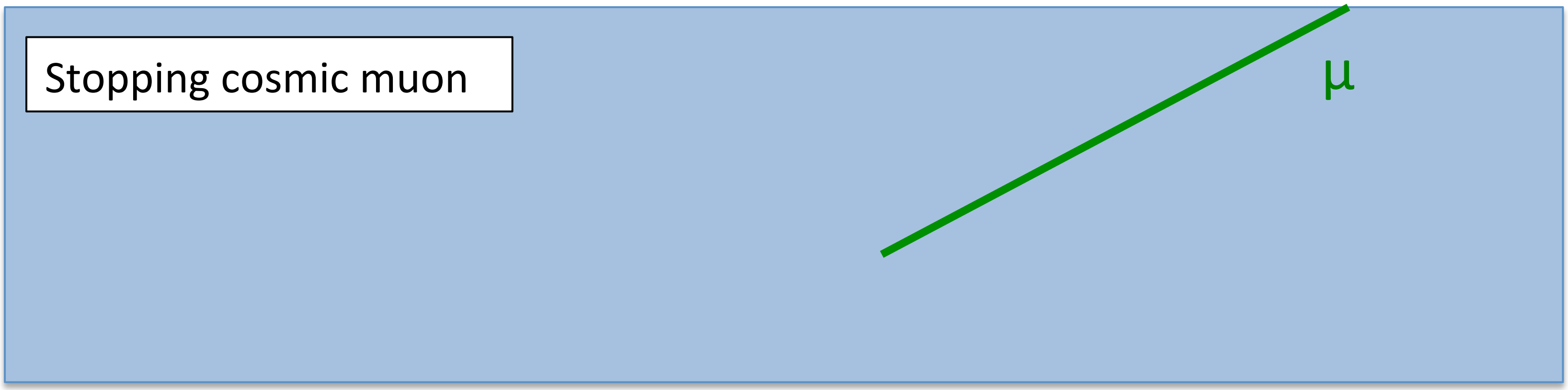
See talk by Marco Del Tutto tomorrow for information on how we reduce/remove these!

Who can find the neutrino interaction?

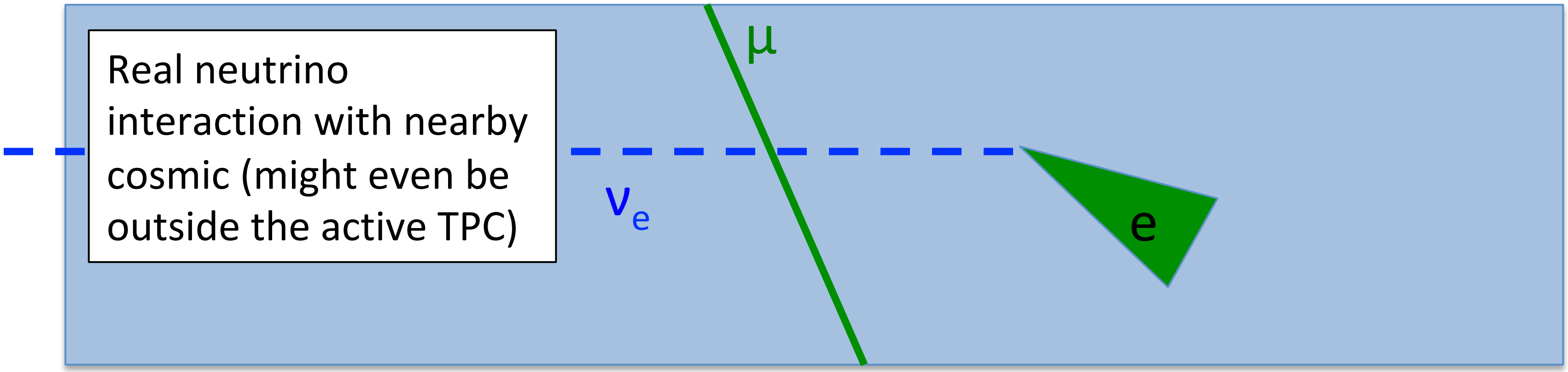


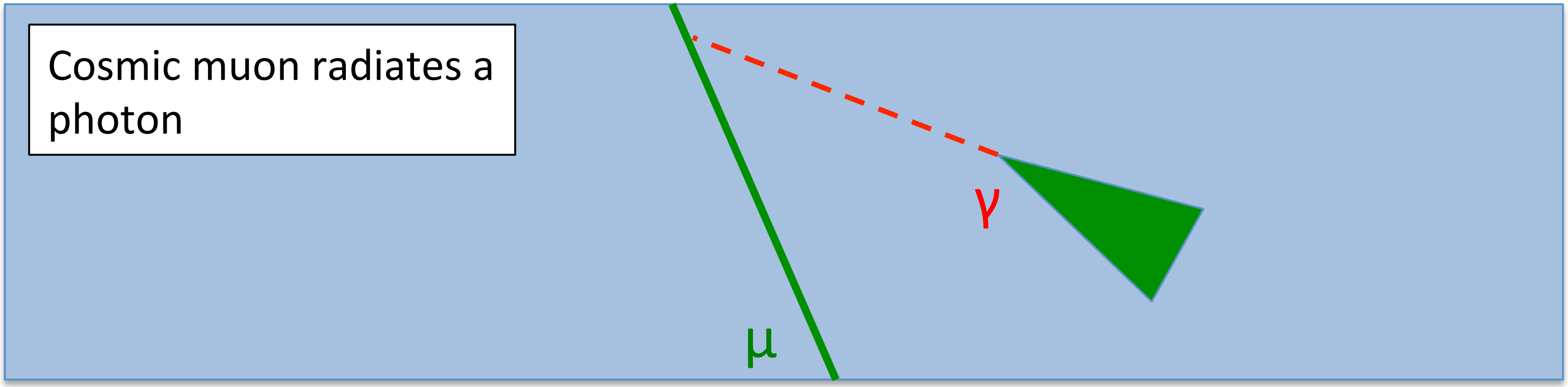
CC0pi signal at MicroBooNE? - numu





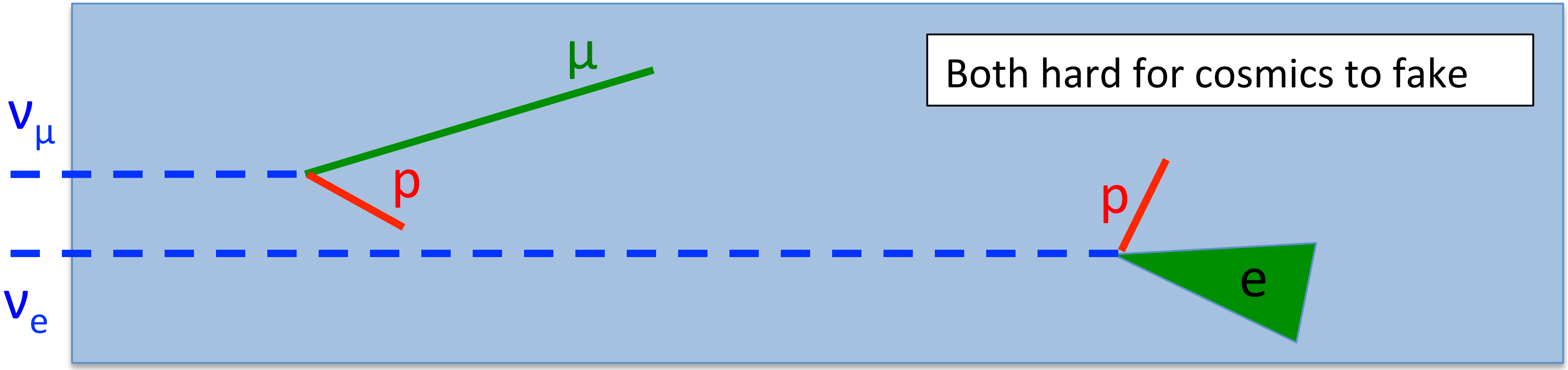
CC0pi signal at MicroBooNE? - nue





Exclusive final states?

- Requiring additional particles significantly reduces cosmic background
- As does requiring containment



MicroBooNE strategy

- We are pursuing multiple strategies
  - **CC-inclusive − cosmic rejection hard**
  - **CC + proton(s) − lower stats,** much lower cosmic background
- For all of these, we build complementary muon- and electron-based selections
- Eventually, we hope to show multiple consistent results
  - Or, if they're inconsistent, we want to be sure it's not because we've missed interaction model problems in one (or more) analysis

An aside on reconstruction

- MicroBooNE are also testing multiple reconstruction paradigms/toolkits:
  - **“Traditional” pattern recognition**
  - **Direct-to-3D** approaches
  - “**Deep learning**” methods
- Different strengths/weaknesses – not clear which will give the best sensitivity, or how model dependence might enter differently

- Proton energy threshold currently <50MeV
  - Pushing this down, can’t really go lower than 20MeV

What are we worried about?

Cosmics:
- Tagging efficiency
- Signal impact
- Time variation
- Spallation?

Detector effects:
- Space charge
- Diffusion
- Lifetime
- Recombination
- Dead/noisy regions?

Modelling uncertainties:
- Energy reconstruction
- Selection efficiency
- Muon/electron differences
- Neutrino backgrounds

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Given the title of this workshop, we'll focus on these!

What models are we using?

- Currently developing analyses using 3 GENIE model tunes
  - Not claiming this is complete
  - What effects are we not able to encapsulate in this list of models?

Model element	Tune 1 (Default)	Tune 2	Tune 3
Nuclear model	Bodek-Ritchie Fermi Gas	Local Fermi Gas	Local Fermi Gas
Quasi-elastic	Llewellyn-smith	Nieves	Nieves
Meson-exchange currents	Empirical	Nieves	Nieves
Resonant	Rein-Seghal	Rein-Seghal	Berger-Seghal
Coherent	Rein-Seghal	Rein-Seghal	Berger-Seghal
FSI	hA	hA	hA2014

Energy reconstruction

- Using LArTPC technology, we should be able to track every particle – **full calorimetric energy reco**
- For CC1p:

$$E_\nu = E_l + E_p - M_p - E_b$$

Note, for different topologies we may be able to do better than this

- For CC-inc:

$$E_\nu = E_l + \Sigma\,(E_p - M_p - E_b) + \Sigma\,(E_\pi)$$

This is assumed in most DUNE oscillation studies

Neutrino energy biases

- We have to correct for invisible energy from
  - Neutrons
  - Protons below threshold
  - Nuclear remnant/breakup (also alphas/deuterons?)
  - Binding energy
- Can we constrain these with other data? Or our data? What should we be measuring?

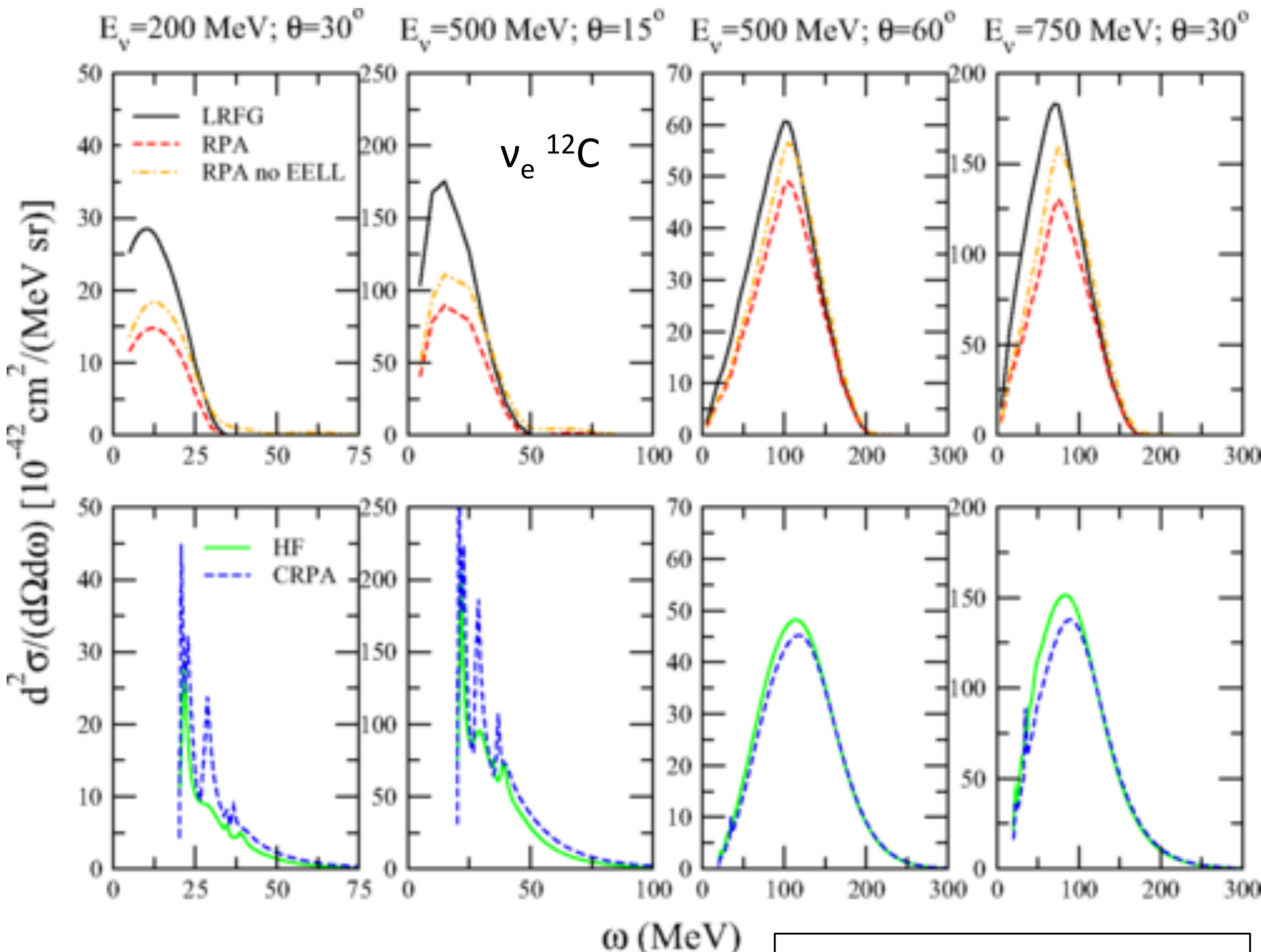
- **What models should we be using to cross check** this?
  - Also, which shouldn't we trust?

muon/electron differences

- Proton threshold
  - energy transfer threshold
    - For a given E_ν, ν_μ and ν_e cross sections integrated over a different omega range
    - Do we understand the impact of this?
- Other effects?
  - **Giant resonances** lead to large differences for similar reasons, but can they produce a proton above threshold?
- FSI – what fraction of events are 0π,Np?
  - muon and electron fluxes are different, feed down due to FSI is different…
- Second-class currents? Radiative effects?

Energy transfer in different models

- Proton threshold implies a cut on this variable
- Different models predict very different shapes!
- **What model should we be considering,** when worrying about this effect?



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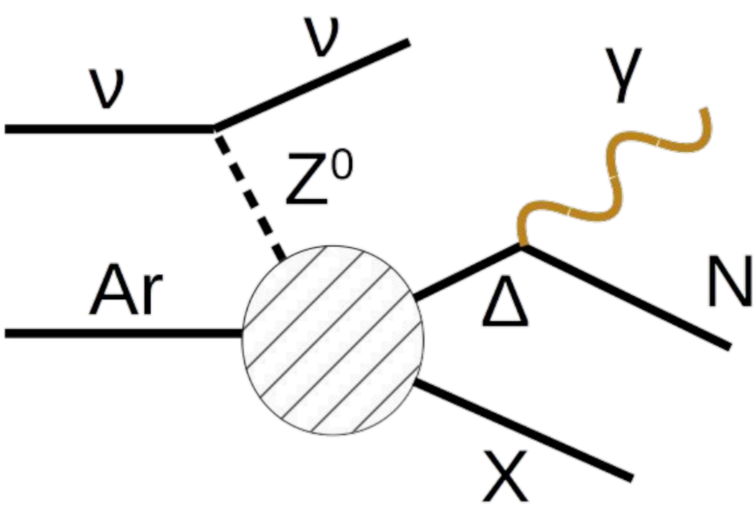
Containment

- Electron showers require containment for energy estimation
  - Still, we will always miss some EM energy which we need to model/correct for
- Not true for muons − 50% leave the TPC
  - We can estimate their momentum from Multiple Coulomb Scattering
  - But, exiting muons look the same as entering cosmics
- **One strategy** is to require the muons are contained − we get a p-theta inefficiency
  - Different between electrons and muons
  - How does this translate to uncertainties due to modelling?
  - **What models should we be looking at** when worrying about this?

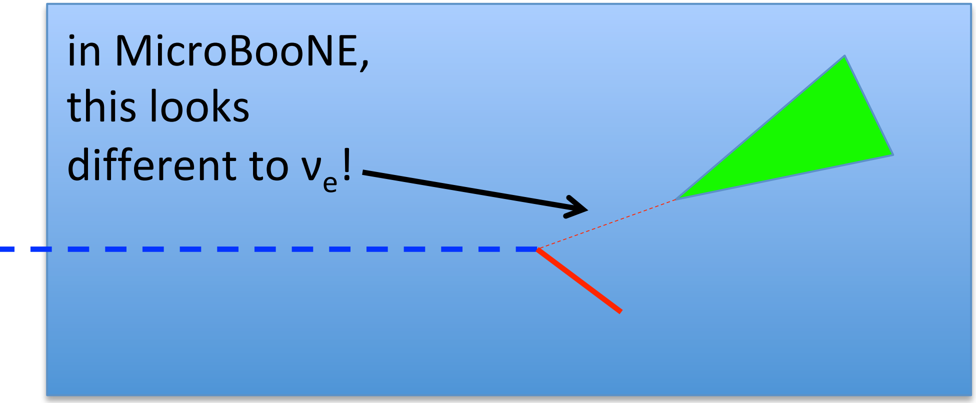
Photons??

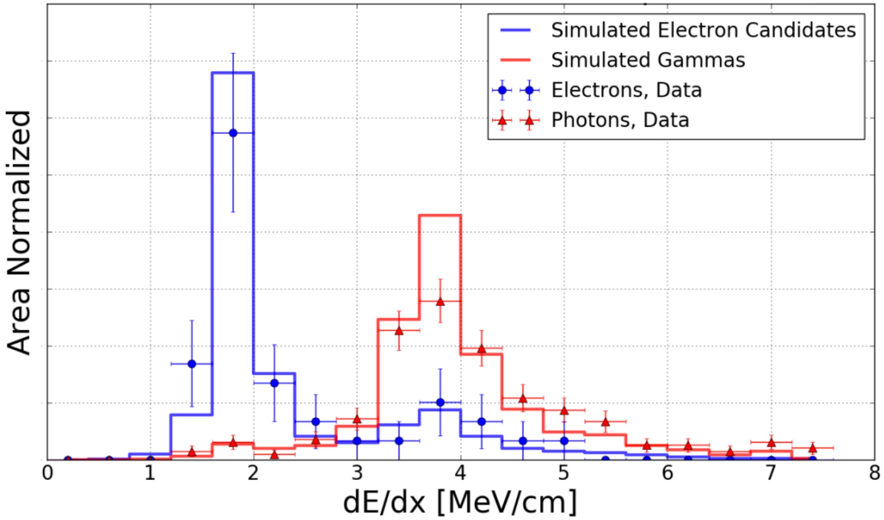
- MiniBooNE can't distinguish electrons and photons
  - NC single gamma was an irreducible background



electron-photon separation

- MicroBooNE measures more about the event than MiniBooNE!
  - Topology – separation between nucleon and photon
  - Shower start dE/dx information





Single photon search methods

- Single photon
  - Most inclusive search
  - Largest cosmic backgrounds

- Single photon + track(s)
  - Track expected to be a proton (from Δ decay)
  - Can attempt to reconstruct Δ mass
  - Smaller cosmic background

Single photon concerns

- Backgrounds:
  - Cosmic photons/electrons
  - neutrino-induced π^0
- Signal model
  - Tracking threshold concerns
    - Expected proton energies?
  - Photon matching to track
    - Decay kinematics?
    - FSI?

We don't have many (signal) models to play with, and we have no neutrino data to guide us

Questions

- What effect or concern have we **not thought of**?
- What is the set of models we should be using a cross checks of potential biases?
  - What model(s) should we not be using?
- What measurements do we need to make in our own data?
  - Nuclear effects in argon
  - Final state interactions
  - See Marco's talk tomorrow

Summary

- The **LArTPC technology provides a huge amount of information** on the final state
- MicroBooNE are pursuing electron-neutrino excess searches using **multiple topological signatures**
  - Also pursuing single-photon production measurements, again with multiple topological signatures
- For exclusive channels, and inclusive selections, we are worrying about various model-dependencies
  - But we are also **asking the community for advice**
  - If you are concerned about us missing something, tell us!